

Alpedrete granite (Spain). A nomination for the “Global Heritage Stone Resource” designation

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Abstract

Alpedrete granite is a monzogranite quarried in the Sierra de Guadarrana (Spanish Central System) foothills in and around Alpedrete, in the province of Madrid, Spain. Used as a building material since the Neolithic, it is one of the most representative of heritage granites of Madrid.

Alpedrete and the surrounding region are characterised by a quarrying culture that has been maintained for centuries. The area is strewn with historic quarries, along with the one presently in operation. Traditional stone cutters who produce hand-finished granite ashlar are still to be found, while others use more modern techniques to achieve new types of products.

Representative monuments including Royal Palace of Madrid, Alcalá Gate and the National Library owe their good conservation state largely to the petrophysical properties and durability of Alpedrete granite. In addition to its use in a substantial number of heritage buildings in Madrid, this stone is also found in most of the city's housing, urban furniture and cobble-stoned streets and nearly all the rural architecture in the Alpedrete area.

This paper discusses the petrological and petrophysical properties of Alpedrete granite, as well as its durability, historic use and quarries, in support of its nomination for the “Global Heritage Stone Resource” designation.

Introduction

The granite in Madrid's *Sierra de Guadarrama*, traditionally commercialised under the name *Piedra Berroqueña*, has been the building stone most widely used in central Spain throughout the region's history. Specifically, a carboniferous (302 M.a) (Villaseca et al., 2012) monzogranite with cordierite as an accessory mineral (Figure 1), has been quarried for centuries at Alpedrete, a town approximately 45 km north of Spain's capital city. This was the stone most frequently chosen for Madrid's built heritage due to the abundance and quality of the material and proximity of the quarries (Fort et al., 2013b). Its role in the city's heritage, along with its petrography, petrophysics, mechanical and aesthetic properties and durability make this granite a worthy nominee for the Global Heritage Stone Resource (GHSR, Cooper, 2013a) designation. The present account of the history and usage of Alpedrete granite and its traditional and modern quarries aims to establish its distinctive identity.

This paper discusses the characteristics and legacy (Table 1) of the stone in sufficient detail for GHSR assessment by the Heritage Stone Task Group (HSTG) Board, as specified in the Task Group's Terms of Reference. HSTG establishment is narrated by Cooper et al. (2013b). Alpedrete granite might be regarded as the first of several dimension stones that could contribute to the *Piedra Berroqueña* region's designation as a "Global Heritage Stone Province".

Alpedrete granite, a grey stone that may contain microgranular mafic nodules (Villaseca et al., 1998), has left its imprint on Madrid's architectural personality and forms part of most of the city's buildings and streets.

Criteria for GHSR recognition

The following description of Alpedrete granite addresses all the features required of GHSR nominations (Cooper et al. 2013a, Hughes et al., 2013).

The importance of granite in the villages around Alpedrete (Figure 2) is mirrored in the stone-related etymology of some of their toponyms. Examples are *Alpedrete* itself (stone in Spanish is *piedra*) and *Berrocal* (in Spanish, an outcrop of granite boulders), while names such as *Moralzarzal* are based on the pre-Roman roots *mor(r)* or *mur(r)*, meaning a pile of stone. These and other villages made stone quarrying their way of life: for centuries with the area's economic activity revolving around granite quarrying, hewing and transport. This long quarrying tradition led to the founding of many small historic, family-run quarries (Figure 3A) where the trade was and still is deeply rooted. The many monuments to the quarryman also attest to the determination to keep stone quarrying traditions alive (Figure 3B).

Alpedrete granite is regarded as a traditional building stone (Fort et al., 2008, 2013b). Any number of scientific articles have been published on its origin (Villaseca et al., 1998, Villaseca and Herreros, 2000, Villaseca et al., 2009, 2012), historic quarries (Fort et al., 2010, 2013b), petrology (Gómez-Heras, et al., 2008), petrophysics (Fort et al. 2011), technical properties and durability (Gómez-Heras, 2005, López-Arce et al., 2010, 2011, Fort et al., 2011), as well as the buildings on which it is found (Fort et al., 2004, 2010, 2013b, Menduiña and Fort, 2005, Pérez-Monserrat et al. 2013).

Alpedrete granite properties

Petrography, petrographic name and commercial designation

Alpedrete granite is an equigranular, medium- to fine-grained monzogranite (Figure 1) consisting of interlocking plagioclase aggregates (20-30 vol. %), quartz (2–5mm and 30-40 vol. %), K feldspar (1–4 mm and 25-35 vol. %) and biotite (2 mm and 10-20 vol. %).

Accessory minerals include ilmenite, apatite, cordierite and zircon.

Alpedrete granite is classified as a monzogranite and commercialised under that same name.

Alpedrete granite have micro-granular mafic enclaves, usually with a tonalite composition show fine-grained porphyritic textures, with phenocrysts commonly of millimetric size.

(Gómez-Heras, et al., 2008).

Chemical composition

The standard chemical analysis of Alpedrete granite given in Table 2 reveals its homogeneity.

Colour

Alpedrete granite is grey, with slight variations in tone. Its chromatic parameters are listed in Table 3. The colour values given are based on the CIELAB scale (1976): lightness (L^*), chromatic coordinates a^* and b^* , whiteness index (WI) and yellowness index (YI), as set out in standard ASTM E313-73.

Natural Variability

Alpedrete area granite has a highly homogeneous quartz, feldspar and mica content and crystal size. Two varieties have been traditionally distinguished. *Piedra Rubia* (blonde stone), so called due to the yellowish tones induced by weathering, is quarried at shallower depths. The second variety *Alpedrete granite*, sensu stricto, is unaltered grey granite. The latter is the variety quarried at present.

Physical properties

Alpedrete granite owes its long durability and resistance to weathering to its physical properties. Table 4 lists the values of these properties as reported by several authors.

Durability

Alpedrete granite is found in heritage buildings that have resisted weathering for centuries. Decay in this stone adopts the form of cracking, surface scaling (Figure 4J), efflorescence, stains or granular disintegration and resulting volume loss. These weathering forms are due primarily to climate, air pollution or the presence of salts (López-Arce et al., 2010, Pérez-Monserrat et al. 2013), in conjunction with factors such as vandalism (Figure 4K). Where microgranular nodules are present (Figure 5D), differential decay may be observed between the nodule and the surrounding rock (Gómez-Heras et al., 2008).

To quantify the decline in petrophysical values, freeze-thaw testing was conducted as specified in European standard EN 12371: 2001 (140 cycles), while salt crystallisation trials were performed further to Spanish and European standard EN 12370: 1999 (30 cycles) (López-Arce et al., 2010.) The variations observed in the stone's petrophysical properties after these ageing tests are given in Table 5.

Laboratory-accelerated decay included surface cracking, generated especially in the feldspar (freeze/thaw test) and biotites (salt crystallisation). Severe decay has been observed in ornamental elements carved from Alpedrete granite on heritage buildings. Such decay is induced by human action: pollution, urination, rust in the iron anchorages used to join ashlar, breakage of downpipes, conservation treatments (Fort et al., 2004, Varas et al, 2007) or the use of inappropriate mortars (Muñoz, 2003).

Quarrying, resource location and supply

Around 400 historic, generally small, shallow quarries (Martín, 1994) (Figures 2 and 3A), where the stone was extracted manually from the surface (to depths of approximately 1-1.5 m), have been located around Alpedrete and surrounding villages. The type of quarrying conducted varied depending on the period. Tors or whale-back boulders were extracted first, and once that resource was depleted, deeper quarrying was undertaken. The largest volumes of stone were extracted from the quarries at El Berrocal and Alpedrete (Figure 2). Beginning in the 1980s, as a result of their inability to adapt to new environmental regulations, many of the small traditional quarries have been closing.

One quarry at Alpedrete whose operations can be traced back for over 100 years is still active. Its 6 000-m³ yearly outputs guarantee the supply of dimension stone.

Historic use

The Neolithic dolmen at Entretérminos between Alpedrete and Collado Villalba, whose remains are still standing was one of the first structures in which Alpedrete granite was used as a building stone. Part of a Roman granite building is preserved at the El Beneficio-Miaccum archaeological site in Collado Mediano. No monumental works were built during the Visigoth period (4th-8th centuries) or none has survived (Menduiña and Fort, 2005). The Muslim era was characterised by the development of materials

such as brick and the reuse of the stone from Roman buildings. It was not until the Christian reconquest of Toledo in 1085 that churches started to be built in central Spain (Figure 3F) with, among other materials, Alpedrete granite. Since building materials were sourced from nearby locations during the Middle Ages (8th-15th centuries), Alpedrete granite was used in the entire area. Widespread use of *piedra Berroqueña* began after King Philip II moved the court to Madrid in 1561. Quarrying was nonetheless most intense at the time in the area around Zarzalejo, SW of Alpedrete, which while forming part of the same pluton (Villaseca et al., 2012), is characterised texturally by larger grain size and mineralogically as a different stone lacking cordierite. It was not until the 18th century that Alpedrete granite became the stone most widely used in and around Madrid and when most of Alpedrete area quarries started to work (Fort et al., 2011). This material was used in many works during the reign of Charles III (1759-1788). It was used to cobble stone avenues and lay gutters, as well as to build monuments such as Madrid's Royal Palace (Figure 4A), Alcalá Gate (Figure 4B), Artichoke Fountain, Prado Museum (Figure 4D) and hospitals such as the one presently bearing the name Queen Sofia. One of the most prominent monuments outside Madrid is the Guadarrama (or Rosario) Bridge (Figure 3I). In the 18th and 19th centuries, Alpedrete granite was generally used in conjunction with the Colmenar limestone quarried in the Madrid basin (Fort et al, 2014), yielding the grey stone - white stone contrast so typical of Madrilenian architecture (Figures 4A, 4B, 4D, 4J and 5F).

The mid- 19th century construction of the Isabel II Canal that carries water to Madrid from the *Sierra de Guadarrama* spurred activity in the Alpedrete area quarries, whose granite was in constant demand to build waterworks (Unceta, 2005) in Madrid such as the Amanuel aqueduct (Figure 3H). Likewise in the 19th century, Alpedrete granite was used in the new city quarters built to accommodate Madrid's expansion. To meet the

strong demand, for 73 years (1883-1956), an 11-km railway line (Aranguren, 1990) operated exclusively to ship Alpedrete granite from El Berrocal (where granite from the nearby Moralarzarzal, Becerril de la Sierra, Cerceda and El Boalo quarries was loaded onto trains) to Collado Villalba (Figure 2). From there it was hauled to Madrid together with granite from other nearby quarries, simplifying and lowering the cost of transport.

With the founding in 1914 of the Sociedad de Sacadores de Piedra de la Sierra (society of stone extractors), whose membership included most of the quarrying villages, and the Sociedad Construcciones Hidráulicas y Civiles (Hydraulic and Civil Construction Society), Alpedrete became the area's leading building stone producer. With the return of the quarries to individual management when these two societies disappeared in 1925, output declined.

Work in the quarries was suspended during the Spanish Civil War (1936-1939). While Alpedrete granite resisted the ravages of war, the bullet holes are visible on the ashlar in some of Madrid's heritage buildings (Figure 4I).

In the 1940s and 1950s, Alpedrete granite was used to rebuild Madrid and, along with other types of granite, the Valley of the Fallen monument. The output of Alpedrete granite rose in the 1960s housing boom, driven by Madrid's rapid population growth.

Today this stone is used primarily in flooring (García del Cura et al., 2008). Other uses include cobblestones, funeral art, and building and monument restoration and rehabilitation across the region of Madrid. The Bank of Spain, rehabilitated in 2003, is but one example (Figure 4E).

Heritage issues

Many of the surnames of the inhabitants of Alpedrete and surrounding quarrying villages can be traced back to other quarrying areas in northern Spain. Because of the huge demand for Alpedrete granite, many workers from the north migrated to the mountains around Madrid to work in the quarries there.

Examples of Alpedrete granite in industrial heritage include grinding stones for flour mills, cones to crush olives (Figure 3E) and mining infrastructure in the former silver mine at Moralarzal (Soto, 2011). Along with brick masonry and granite rubble, Alpedrete granite is one of the materials that was used to build the grid of optical telegraph towers (1844). An Alpedrete granite tower has been conserved at Collado Mediano, although the 2008 restoration concealed the original masonry bond (a mix of brick and coursed rubble masonry) (Figures 3C-C'). Many examples of traditional rural architecture are also well preserved, including sheds, washing places (Figure 3G), drinking troughs, irrigation canals and boundary walls (Figure 3D). The Alpedrete granite-related heritage has been turned to value in the form of Geomonumental routes (<http://www.madrimasd.org/English/Science-Society/scientific-heritage/Geomonumental-Routes/default.asp>), a platform that introduces the general public to the geological characteristics and cultural value of buildings bearing Alpedrete granite. These socially beneficial activities have been conducted on site in recent years in the framework of Madrid's Science Week.

Buildings

Alpedrete granite is found in 75 % of Madrid's cultural heritage assets. It was also used in nearly all heritage industrial buildings, housing in the city's traditional quarters, indoors it was used in steep steps of stairs, chimneys and outdoors, in dados or window frames, walkways,

statues, fountains, milestones and urban furniture (Figures 4 and 5). Table 1 lists the most representative monuments built with Alpedrete granite, together with other types of building stone (Fort et al., 2002, Gómez-Heras and Fort, 2004).

Alpedrete granite vulnerability and maintenance

Thanks to its petrological and petrophysical characteristics, Alpedrete granite is highly resistant to the agents of decay (and consequently durable), usable with a variety of finishes and readily cleaned.

Pre-quarrying decay, gloss (micro-roughness), finish and position on buildings, however, condition the type of maintenance or cleaning required. The method used should not roughen the granite surface and special care should be taken in aged *piedra Rubia* quarried from very shallow tors where the feldspars and micas may have been significantly altered by the action of fluids and concomitant hydrolysis. In this process, potassium feldspar is replaced by kaolinite, plagioclase is converted to sericite and chloritization of biotite. Hydrolysis may also release iron from biotite. Cordierite alteration, in turn, yields pinite or micaceous clusters that decay more quickly, although cordierite is only rarely present in Alpedrete granite (Fort et al. 2013**b**).

Suitability

The low anisotropy, capillary water absorption, porosity and high mechanical strength and durability (Tables 4 and 5) characterising Alpedrete granite render the stone exceptionally moisture-resistant. For that reason it has traditionally been used in pedestals, dados (Figure 5G) and building façades. Its scantily fractured outcrops are particularly suitable for carving very large columns and lintels (Figure 4). It is used not only in structural members, but also in ornamental elements, especially around doors and

windows (Figures 4C, 4G), chimneys (Figure 4F), pinnacles atop buildings, and to make bollards. This stone has also been used for cobblestones (Figure 5B), walkway kerbs (Figures 5A, 5B) (Martín, 1994), manhole lids (Figure 5C), wells, spur stones (Figure 5D), retaining walls, corner protectors, decorative (Figure 5E) and functional (Figure 5F) fountains, benches (Figure 5H) and milestones (Figure 5I) that are present throughout Madrid.

As may be deduced from the foregoing, Alpedrete granite meets all the requisites for a GHSR nomination. Its designation would contribute to raising awareness of historic and modern features essential to its conservation, while furthering more efficient use of this dimension stone as a restoration material in the heritage monuments it was used to build.

Acknowledgements

This study was funded by the Community of Madrid under the GEOMATERIALS 2 project (S 2013/MIT-2914). The authors are members of the Complutense University of Madrid's Research Group: "Alteración y Conservación de los Materiales Pétreos del Patrimonio" (ref. 921349). The petrophysical assessments were run at the IGEO Petrophysical Laboratory, affiliated with the Moncloa Campus of International Excellence (UCM-UPM) Heritage Laboratory Network (RedLabPat). The assistance, input and support provided by laboratory technicians Carmen Vázquez and Blanca Gallardo are gratefully acknowledged. Manuscript edited by Margaret Clark, professional translator and English language science editor.

References

Aidico 2012 Informe Sectorial de la Piedra Natural en España 2012, Observatorio del mercado de la piedra natural. Instituto tecnológico de la Construcción.

Aranguren, J., López Bustos, C. 1990, El ferrocarril de Villalba a El Berrocal: Carril, v. 29, pp. 43-51.

Brandebourger, E., 1984, Les granitoides Hercyniens tardifs de la Sierra de Guadarrama Systeme Central Espagne. Petrographie et geochemie: PhD Thesis, Universite Lorraine, pp. 209.

Cooper, B.J., 2010, Toward establishing a “Global Heritage Stone Resource” designation: Episodes, v. 33, no. 1, pp. 38-41.

Cooper, B.J., Marker B.R. and Thomas I.A., 2013a, Towards International Designation of a Heritage Dimension Stone: Key Engineering Materials, v. 548, pp. 329-335.

Cooper, B.J., Marker, B.R., Pereira, D. and Schouenborg, B., 2013b, Establishment of the “Heritage Stone Task Group” (HSTG): Episodes, v. 36 no. 1, pp. 8-9.

EN 12370:1999. Natural stone test methods, Determination of resistance to salt crystallisation. AENOR (Spanish Association for Standardisation and Certification), 10 pp.

EN 12371:2011 Natural stone test methods, Determination of frost resistance, AENOR (Spanish Association for Standardisation and Certification), 16 pp.

Fort, R., Bernabéu, A., García del Cura, M.A., Ordoñez, S., López de Azcona, M.C. and Mingarro, F. 2002. Novelda Stone: a stone widely used within the Spanish architectural heritage, *Materiales de Construcción*, 52, 266, 19-32.

Fort, R. Alvarez de Buergo, M., Mingarro Martín, F., López de Azcona, M.C., 2004, Stone decay in 18th century monuments due to iron corrosion. *The Royal Palace, Madrid (Spain): Building and Environment*, v. 39, pp. 357–364.

Fort, R., 2008, La Piedra Natural y el Patrimonio construido: Un mismo campo de investigación: *Mater. Construcc*, v. 58, no. 7-10, pp. 289-290, ISSN: 0465-2746.

Fort, R., Alvarez de Buergo, M., Perez-Monserrat, E.M., Varas M.J., 2010, Characterisation of monzogranitic batholiths as a supply source for heritage construction in the northwest of Madrid: *Engineering Geology*, v. 115, pp. 149–157.

Fort, R., Varas M J, Alvarez de Buergo, M. and Freire-Lista, D.M., 2011, Determination of anisotropy to enhance the durability of natural stone: *Journal of Geophysics and Engineering*, v. 8, pp. 132–144.

Fort, R., Alvarez de Buergo, M. and Perez-Monserrat, E.M., 2013a, Non-destructive testing for the assessment of granite decay in heritage structures compared to quarry stone: *International Journal of Rock Mechanics & Mining Sciences*, v. 61, pp. 296–305.

Fort, R., Alvarez de Buergo, M., Pérez-Monserrat, E.M., Gómez-Heras, M., Varas-Muriel, M.J. and Freire-Lista, D.M., 2013b, Evolution in the use of natural building stone in Madrid, Spain: *Quarterly Journal of Engineering Geology and Hydrogeology*, v. 46, pp. 421-429.

Fort, R., Varas-Muriel, M.J., Alvarez de Buergo, M., Perez-Monserrat, E., 2014, Colmenar Limestone, Madrid, Spain: considerations for its nomination as a Global

Heritage Stone Resource due to its long term durability Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones: Geological Society of London. Special Publications, v. 407, first published online September 3. 2014. doi: 10.1144/SP407.8

García del Cura, M.A., Benavente, D., Bernabéu, A., Martínez-Martínez, J., 2008, The effect of surface finishes on outdoor granite and limestone pavers: *Materiales de Construcción*, v.58, no. 289-290, pp.65-79.

Gómez-Heras, M., 2005, Procesos y formas de deterioro térmico en piedra natural del patrimonio arquitectónico: Phd Thesis, Universidad Complutense de Madrid, pp. 339.

Gómez-Heras, M., Smith, B.J., Fort, R., 2008, Influence of surface heterogeneities of building granite on its thermal response and its potential for the generation of thermoclasty: *Environ Geol*, v. 56, pp. 547–560.

Hughes, T., Lott, G.K. Poultney, M.J. and Cooper, B.J., 2013, Portland Stone: A nomination for “Global Heritage Stone Resource” from the United Kingdom: *Episodes*, v. 36, n. 3, pp 221-226.

Llorente Pinto, J.M., 2011, El valor indicador de los topónimos. El caso de la voz berrocal y sus variantes: *Asociación de Geógrafos Españoles Bulletin*, v. 56, pp. 50-77.

López-Arce, P., Varas-Muriel, M.J, Fernández-Revuelta, B., Álvarez de Buergo, M., Fort, R., Pérez-Soba, C., 2010, Artificial weathering of Spanish granites subjected to salt crystallization tests: Surface roughness quantification: *Catena*, v. 83, pp. 170–185.

López-Arce, P., Fort, R., Gómez-Heras, M., Pérez-Monserrat, E., Varas-Muriel, M.J., 2011, Preservation strategies for avoidance of salt crystallisation in El Pualar Monastery cloister, Madrid, Spain: *Environ Earth Sci*, v. 63 pp. 1487–1509.

Martín Moreno, S., 1994, *Materiales Pétreos Tradicionales de Construcción en Madrid*. Phd Thesis, Universidad Politécnica de Madrid, pp. 772.

Mendiña, J., and Fort, R. (coordinators), 2005, Las piedras utilizadas en la construcción de los Bienes de Interés Cultural de la Comunidad de Madrid anteriores al siglo XIX. IGME-IGE, Madrid, pp.131.

Muñoz Cebrián, J.M., 2003. Fenómenos biogeoquímicos de las piedras monumentales: Biblioteca Nacional y Museo Arqueológico Nacional de Madrid: *Ingeniería Civil*, v. 129, pp. 103-110.

Pérez, P.P., Navarro, J.V., Sánchez, A., 2008, Incidencia del empleo de morteros de azufre en edificios del siglo XIX: daños producidos en la valla perimetral de la Biblioteca Nacional y del Museo Arqueológico Nacional. *Bienes culturales: Instituto del Patrimonio Histórico Español Journal*, v. 8, pp. 167-180.

Pérez-Monserrat, E.M., Fort, R., 2004, Caracterización y procedencia de la sillería granítica del convento de la Encarnación, Madrid: *Geotemas*, v. 6, no.1, pp. 89-92.

Pérez-Monserrat, E.M., Fort, R., Álvarez de Buergo, M., Varas, M.J., 2008, Rutas Geomonumentales: La Geología para la enseñanza y difusión del patrimonio arquitectónico: *Tierra y Tecnología*, v. 33, pp. 39-46.

Pérez-Monserrat, E.M., Fort González, R., Álvarez de Buergo, M., Varas-Muriel, M.J. and Gómez-Heras, M., 2013, Los materiales pétreos utilizados en la obra de Antonio Palacios como apuesta para la conservación del patrimonio geológico: *Tierra y Tecnología*, v. 43, pp 28-34.

Pérez-Monserrat, E.M., Alvarez de Buergo M, Gómez-Heras M, Varas Muriel MJ, Fort, R., 2013, An urban geomonumental route focusing on the petrological and decay features of traditional building stones used in Madrid, Spain: *Environ Earth Sci.*, v. 69, pp. 1071–1084.

Soto Caba, M.A., 2011, Las minas de plata de Moralarzal (comunidad de madrid) en los siglos XVI y XVII: *De Re Metallica*, v. 16, pp. 11-19.

Unceta, M., Echenagusia, J., 2005, Madrid: la sierra del agua: guía turística del Canal de Isabel II: Santillana Ediciones generales. El País/Aguilar, pp 220.

Varas, M.J., Alvarez de Buergo, M and Fort, R., 2007, The Influence of past protective treatments on the deterioration of historic stone façades. A case study: *Studies in conservation*, v. 52, pp. 110-124.

Villaseca, C., Barbero, L., Rogers, G., 1998, Crustal origin of Hercynian peraluminous granitic batholiths of central Spain: petrological, geochemical and isotopic (Sr, Nd) constraints: *Lithos*, v. 43, pp. 55–79.

Villaseca, C., Herreros, V., 2000, A sustained felsic magmatic system: the Hercynian granitic batholith of the Spanish Central System: *Trans. R. Soc. Edinburgh: Earth Sci.*, v. 91, pp. 207-219.

Villaseca, C., Bellido, F., Perez-Soba, C. and Billstrom, K., 2009, Multiple crustal sources for post-tectonic I-type granites in the Hercynian Iberian Belt: *Mineralogy and Petrology*, v.96, pp. 197–211.

Villaseca, C., Orejana, D., Belousova, E.A., 2012, Recycled metagneous crustal sources for S- and I-type Variscan granitoids from the Spanish Central System batholith: Constraints from Hf isotope zircon composition: *Lithos*, v. 153, pp. 84–93.

Table 1. Representative monuments in the Madrid region built with Alpedrete granite and other types of stone

Building	Year built	Fountains	Year built
Dolmen at Entretérminos	2500-3000 BCE	F. of Titans	1657
El Beneficio-Miaccum Roman archaeological site	Before the 4 th century	F. of Fame	1731
Asunción de Nuestra Señora Church at Alpedrete	12 th -13 th centuries	F. of San Antón	1770
Toledo Bridge	1719-1732	Artichoke F.	1781
Madrid's Royal Palace	1738-1764	Galapagos F.	1832
Façade on San Nicolás de los Servitas Church	1740 aprox.	King Philip IV F.	1843
Prado Museum	1785-1808	Fallen Angel F.	1880
Alcalá Gate	1770-1778	F. of the Shell	1969
House of the Five Major Guilds	approx. 1789	Sculptures	Year sculpted
Royal Theatre in Madrid	1830-1850	Hercules and the Lernean Hydra	1650
National Library	1866-1892	Obelisk to the 2 nd of May	1821
Bank of Spain	1884-1891	Queen Isabel	1883
Cervantes Institute	1925-1929	Monument to King Alfonso XII	1901
Joint Ministry Headquarters	1933-1942	Miguel de Cervantes	1916
Valley of the Fallen Monument	1940-1958	Princess Isabel de Borbón	1953
Addition to the Bank of Spain	2003	Jacinto Benavente	1961

Table 2. Mean chemical composition of Alpedrete granite (Villaseca et al., 1998).

Chemical analysis: majority elements in Alpedrete granite (wt%)										
SiO₂	TiO₂	Al₂O₃	Fe₂O₃	FeO	MnO	MgO	CaO	Na₂O	K₂O	P₂O₅
69.60	0.4	15.02	2.97	1.54	0.05	0.96	2.45	3.32	3.89	0.16

Table 3. Chromatic parameters for Alpedrete granite

Alpedrete granite	
L*	67.4 ± 3.5
a*	-0.7 ± 0.3
b*	1.0 ± 0.8
YI	1.8 ± 1.6
WI	34.5 ± 3.8

Table 4. Physical properties in Alpedrete granite (AL). (1) Mendiuña and Fort., 2005, (2) Fort et al., 2011, (3) Fort et al. 2013b.

Property	Value
Impact strength (cm)	68±14 ⁽¹⁾
Compressive strength (MPa)	136.9±41 ⁽¹⁾
Bending strength (MPa)	8.88±3.69 ⁽¹⁾
Bulk density (Kg/cm³)	2669±17 ⁽²⁾
Water absorption (%)	0.3±0.0 ⁽²⁾
Capillary absorption coefficients (g·m⁻²·s^{-0.5})	1.523 to 3.1983 ⁽²⁾
Porosity accessible to water (%)	0.8±0.1 ⁽²⁾
Mercury intrusion porosity (%)	0.5 ⁽³⁾
Frost resistance (%)	0.01 ⁽¹⁾
Ultrasonic P-wave velocity (m/s)	4 601±204 ⁽²⁾
dM (%)	5.8 ⁽³⁾

Table 5. Petrophysical properties in Alpedrete granite before and after 140-cycle freeze-thaw and 30-cycle salt crystallisation testing. Vp: ultrasonic P-wave velocity; Δ: property variation, measured in percentage. (1) López-Arce et al., 2010.

Property	initial value	After 140-cycle freeze-thaw test	Δ (%)	After 30 cycle-salt crystallisation test	Δ (%)
Porosity accessible to water (%)	0.8±0.08 ⁽¹⁾	-	-	1 ⁽¹⁾	25.0
Bulk density (kg/m³)	2 668±18 ⁽¹⁾	2666±12	0.06	2 660 ⁽¹⁾	-0.3
Vp (m/s)	4 620±163 ⁽¹⁾	4 525±139	2.0	4445 ⁽¹⁾	-3.8
Mercury intrusion porosity (%)	0.44 ⁽¹⁾	0.62	40.9	1.01 ⁽¹⁾	129.5
Microporosity < 5 μm (%)	0.31 ⁽¹⁾	0.48	54.8	0.32 ⁽¹⁾	3.2
Macroporosity > 5 μm (%)	0.13 ⁽¹⁾	0.14	7.7	0.69 ⁽¹⁾	430.8

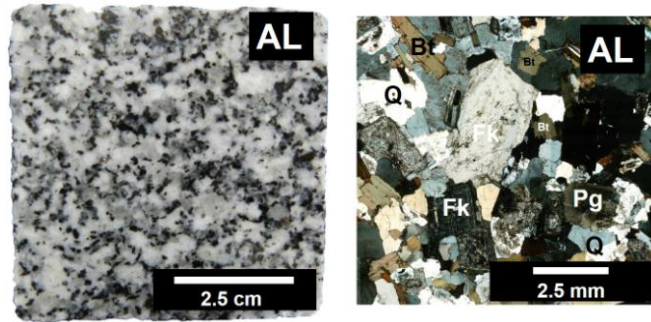


Figure 1. Alpedrete granite from historical quarries: left, macroscopic image; right, thin section petrographic image: Bt: biotite, Pg: plagioclase, Q: quartz, FK: potassium feldspar.

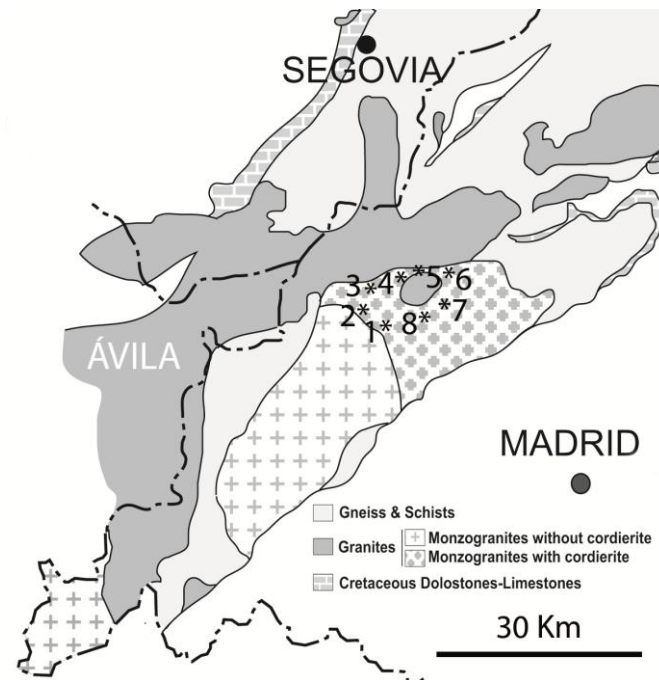


Figure 2. *Piedra Berroqueña* province (Fort et al., 2013b modified) showing the location of the historic Alpedrete granite quarries: (1) Alpedrete, (2) Collado Mediano, (3) Becerril de la Sierra, (4) Mataelpino, (5) El Boalo, (6) Cerceda, (7) El Berrocal, (8) Moralarzal.

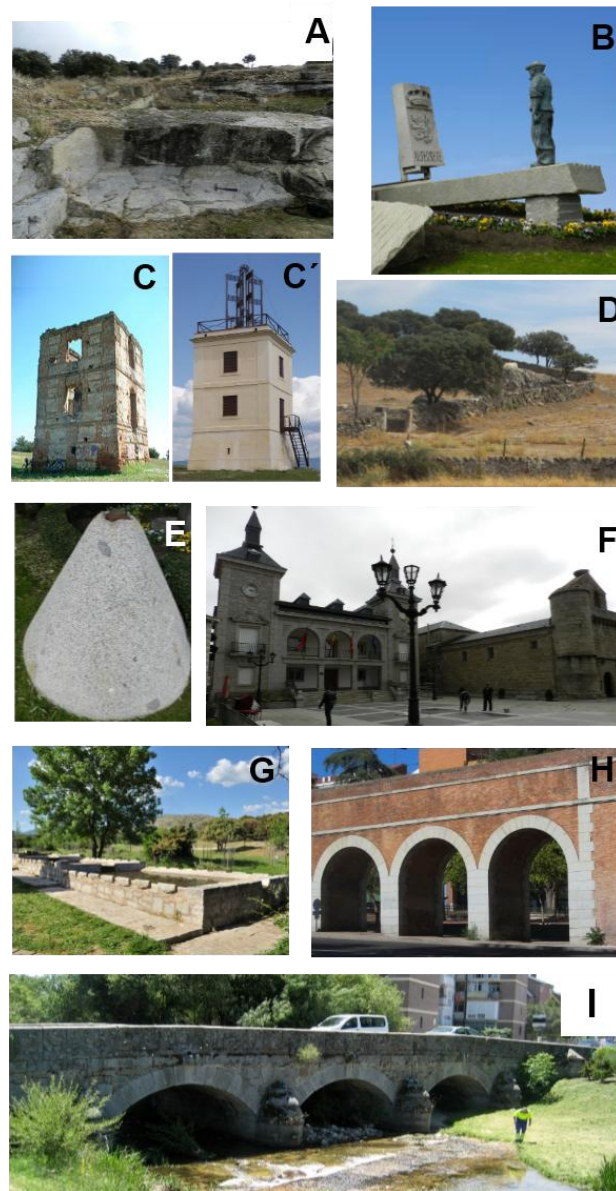


Figure 3. (A) Alpedrete historic quarry, front, (B) Monument to the quarryman, Alpedrete, (C) Optical Telegraph Tower at Collado Mediano before conservation-restoration works, (C') After conservation-restoration works, (D) Typical granite boundary wall in Alpedrete, (E) Cone for crushing olives, (F) City Hall, Alpedrete (1959) and Asunción de Nuestra Señora Church (12th-13th centuries); (G) Washing place, Alpedrete, (H) Amaniell aqueduct, (I) Rosario Bridge, second half of 17th century.



Fig. 4. Monuments built with Alpedrete granite:

- (A) Façades, Royal Palace at Madrid, (B) Alcalá Gate, (C) Portal, San Nicolás de los Servitas Church, (D) Façade, Prado Museum, (E) Bank of Spain, (F) Chimney, Royal Palace at Aranjuez, (G) Detail of window ornament, (H) Façades, Cervantes Institute, (I) Ashlars damaged by bullets during the Spanish Civil War, (J) Surface scaling on enclosure wall, (K) Ashlars soiled by graffiti.

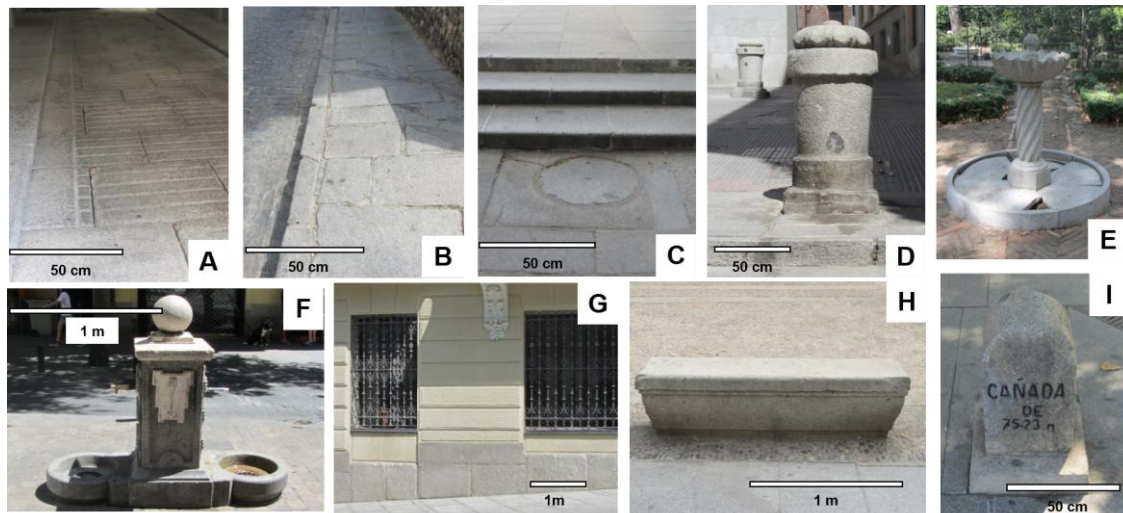


Figure 5. Alpedrete granite on Madrid streets and thoroughfares:

(A) Walkways, kerbs and carriageway, (B) Walkway, kerb and cobblestones, (C) Staircase, street paving and sewage system cover, (D) Spur stone with nodule, (E) Ornamental fountain, (F) Functional fountain (Alpedrete granite and Colmenar limestone), (G) Dado on traditional building, (H) Bench, (I) Milestone on cattle route, Madrid.